1900

The Use of Blast Furnace Gases in Gas Engines

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CHEMICAL SECTION.

Stated Meeting, October 25, 1900.

THE USE OF BLAST FURNACE GASES IN GAS ENGINES.

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Practical gas engines were first put into operation by Otto, in 1870. They were for many years made only of small powers, 1 to 10 or, at most, 20 horse-power. The fuel used was illuminating gas, which has the high calorific power of 4,500 to 5,000 calories per cubic meter. About 1886, experiments showed that weaker gas could be used, and that if the gas and air mixture was strongly compressed in the cylinder before explosion, the ignition never failed. This gave rise to the running of gas engines by producer gas, particularly that made by the auxiliary use of steam, and therefore carrying considerable hydrogen. Such gas is in reality a mixture of normal producer gas with water gas; it is sometimes called Dowson gas, after the Dowson producer. It may carry 5 to 15 per cent. of hydrogen, and its calorific power vary between 1,000 and 1,500 calories per cubic meter. The use of this gas in large engines, up to 200 horse-power, gave an efficiency of 1 horse-power per 1 pound of coal per hour, and is even at present the most efficient method of generating mechanical power from coal.

The next step was a natural one; it was a consideration of the question: "Can blast furnace gases be used in gas engines?" As far as I can find, the question was first taken up practically by B. H. Thwaite, a British engineer, in 1894. Before considering his investigations, let us imagine the conditions which bear on the case.

(1) Blast furnace gases are not as rich as illuminating gas or even as producer gas, not even as rich as the poorest regular producer gas. Average analyses of rich and poor producer gas and blast furnace gases would be about as follows, in percentages by volume; on dried gas:

	Dowson Gas.	Siemens Gas.	Blast Furnace Gas.
Hydrogen	8	2	2
Hydrocarbons	2	2	2
Carbonic oxide	33	28	24
Carbonic acid	3	3	12
Nitrogen	58	65	60
Percentage of combustibles	43	32	28
Calorific power per cubic meter	1,400	1,100	950

The conclusions drawn from this comparison would be that it would be a more difficult problem to secure unfailing ignition of blast furnace gases. Indeed, the quality of these gases varies at times so greatly that they can scarcely be burnt under boilers. Any use of these gases in gas engines must therefore face this possibility of very poor gas, and provide exceptional means to secure unfailing ignition of very poor mixtures. Another incidental conclusion would have been that for a given power the engines using blast furnace gas must be larger, because of the decreased calorific power of the gases.

(2) Blast furnace gases are very dusty, from particles of the charge, and impure with metallic and saline vapors. Any prospective use in gas engines must consider this difficulty, and either provide for efficient cleaning of the gas, or provide an engine which is not affected by the dust or corroded

by the saline vapors. Cleaning of the gas would naturally recommend itself as the most likely to succeed in overcoming this obstacle.

(3) There is usually 5 to 10 per cent. of vapor of water in blast furnace gases, which would decrease the expansive force of the explosion and so decrease the power of the engine. A removal of the water vapor by condensation would appear desirable.

(4) Gas engines run ordinarily at 200 revolutions per minute, or more, while blowing engine cylinders run at 25 to 40. Gas engines, therefore, would not appear capable of supplying blast for furnaces without using gearing or other means of reducing the speed, or else by making a radical reduction in the speed of running the engines or a radical increase in the speed of the blowing cylinder. Meanwhile, until these are attained, the gas engines are suited only for higher speed machinery than blowing engines.

Such as above outlined would have been the conditions and problems confronting the investigator in this field six years ago. We will now pass on to consider how these difficulties, real and prospective, have been overcome.

B. H. Thwaite applied for a British patent on May 2, 1894 (granted May 2, 1895, No. 8670), which described methods of purifying blast furnace gas preliminary to using it in gas engines; the methods being, briefly, to take the gases from the furnace in such a manner that as little dust and metallic vapor passes into the down-comer as is possible, and as much combustible gas; then filtering the gas through wet columns of coke or brushwood, and screening it through sawdust, powdered asbestos or a fine wire screen. The claims are for using the special purifying apparatus described, in combination with thermo-dynamic motors, etc.

Mr. J. Riley* says that he was acquainted with this proposal of Thwaite in the autumn of 1894, and in February, 1895, arranged for a 15 horse-power engine to be set at work on gas thus purified, at Wishaw, Scotland. This motor ran some light machinery very successfully, and

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**Journal Iron and Steel Inst.*, 1898, I, 33.

delivered in indicated horse-power the equivalent of 20 per cent. of the thermal value of the gases burnt. This was the first motor run on blast furnace gas. Its successful operation inspired W. H. Watkinson to read a paper on the subject before the West of Scotland Iron and Steel Institute, on March 15, 1895,* in which he discusses the power to be saved by a furnace making 100 tons of pig iron a day, as something like 6,000 horse-power, an amount quite startling, and, it must be said, much too large. The average saving will be about one-half that amount. Still, this is the first public announcement of the successful experiment and of the possibilities which it revealed.

Since 1895, numerous small motors have been in operation in Great Britain, using purified blast furnace gas. They have been mostly of 10 to 40 horse-power, but more recently up to 200, driving machinery and dynamos, but not blowing engines. In the development of large motors and their adaptation to blowing engines the Continent, and more particularly Belgium, has taken the lead.

In the beginning of 1895 experiments were also undertaken in France with small Deboutteville gas engines, but without much success, so that no records of the results attained were made public. Bailly and Kraft, however, engineers at the John Cockerill Works, at Seraing, Belgium, were sanguine of success, and installed a 4 horse-power Deboutteville motor, which began operations in December of that year, being nearly ten months after Thwaite's success in England. This motor worked steadily for eighteen months, an average of sixteen hours daily, using purified blast furnace gas. The analyses of Witz showed that the quality of the gases did not vary so much as had been anticipated, and rather approximate measurements of the efficiency showed a total of 12 per cent. After four months' running the cylinder was found to be clean, it appearing that the dust in the gases was all thrown out in the white smoke of the exhaust. No corrosive action in the cylinder was observed after two years' use.

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* *Journal Iron and Steel Inst.*, 1895, II, 471.

Encouraged by these results, drawings were prepared in 1897 for a 200 horse-power motor of the "Simplex" single-cylinder type, a four-cycle machine. This engine was put in operation in April, 1898, and a description of its installation given by Mr. A. Greiner, Director-General of the Cockerill Society, before the Iron and Steel Institute, on May 5, 1898;* while a report on its working was made by Witz to the same society August 26, 1898.† Greiner said in his announcement: "When a 200 horse-power engine has run successfully for six months, manufacturers will be emboldened to put up one of 500 or 800 horse-power to drive the blowing engines for a blast furnace or converter plant, and thence to a rolling mill engine is an easy advance."

The report of Witz, three months later, was eminently favorable. The tests had been made by Witz, together with Professor Hubert, of Liege University, engineers Bailly and Kraft, of the Cockerill Company, and Deboutteville, the gas engine builder. The gas was passed through three pairs of coke scrubbers, and then straight to the engine through a gas holder of 300 cubic meters capacity. Its calorific power varied from 800 to 1,000 calories, and averaged 981 per cubic meter. The cylinder was 0·8 meter diameter by 1·0 meter stroke, and the gas-air mixture was compressed to 7·5 atmospheres pressure before ignition. Fly-wheel, 15 tons. The detailed figures obtained were for a 24-hour run:

Average velocity	105·2 revolutions per minute.
Effective horse-power	181·2
Water used in cylinder jacket . .	72·0 kilos per horse-power hour.
Oil used for lubricating	15· grams per horse-power hour.
Grease used for lubricating . . .	2·3 " " " "
Temperature of water raised . .	11·0° C.
" " discharge . . .	480° to 510° C.
Consumption of gas	3·33 m³ per horse-power hour.
Thermal efficiency	19·5 per cent.

The report remarks that "the engine works as regularly as a steam engine, and the dust in the gas is in no way injurious to its continual operation."

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* *Journal Iron and Steel Institute*, 1898, I, 21.

† *Journal Iron and Steel Institute*, 1898, II, 130.

This engine has been steadily at work now for over two years, driving a dynamo for power purposes day and night, without any wearing out of the parts, the interior of the cylinder showing only a very thin brown skin, which in no wise affects the working of the piston or the efficiency.

Calculations based on the figures obtained with this engine showed that at the Seraing furnaces, making 600 tons of pig iron daily, the gases were producing through steam boilers and engines 2,300 horse-power, with a thermal efficiency of 2·5 per cent. The same gases used in gas engines at an efficiency of 20 per cent. would be capable of developing 18,400 horse-power, leaving a surplus of 16,000 horse-power available for other purposes, which is at the rate of 2,667 horse-power surplus per 100 tons of pig iron made per day.

These surprising figures and the success already achieved stimulated experiments in Hoerde, Germany, and Differdingen, Luxembourg. At Hoerde the Deutz motor was tried, and at Differdingen a "Simplex" engine. The Cockerill Company, however, again took the initiative, and, in 1899, had constructed the largest single-cylinder gas engine ever built, connected to a blowing cylinder for furnishing blast. The engine was designed and constructed by Deboutteville, and was started on November 2, 1899. On May 9, 1900, Mr. A. Greiner described the engine to the Iron and Steel Institute,* and gave the results attained by six months' continuous working. The details are highly interesting, since this is the first gas engine to run the blowing machinery of its own furnace. They are, in abstract, as follows:

DIMENSIONS.

Diameter gas cylinder	1·3 meters (51 inches).
Stroke " "	1·4 " (55 ").
Speed	80 r. p. m. normally.

PRESSURE OF BLAST SUPPLIED.

At 84 r. p. m.	40 centimeters of mercury	(7·75 lbs. per in.).
" 94 " "	45 " " "	(8·75 " " ").
" 62 " "	62 " " "	(12·0 " " ").

*Journal Iron and Steel Institute, 1900, I, 109.

POWER DEVELOPED.

561 to 725 effective horse-power in the blast cylinder.

GAS USED.

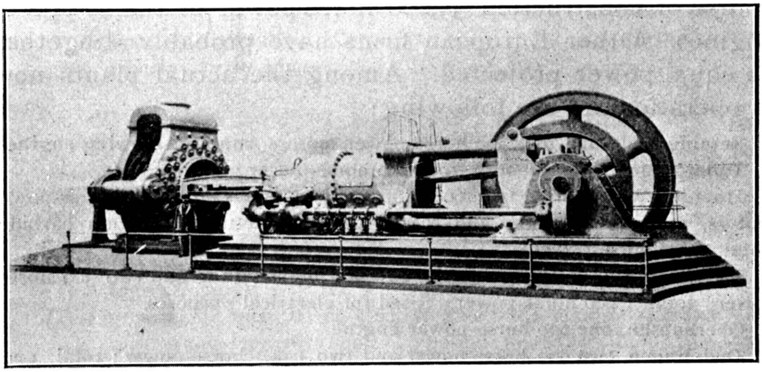
2·86 m^3 per effective horse-power hour.
2·33 m^3 " indicated " "

EFFICIENCY.

28·7 per cent. as indicated horse-power.

A consideration of the distribution of the heat energy showed approximately:

Converted into work in the cylinder	30 per cent.
Carried away by the cooling water	50 " "
" " in the escaping gases	20 " "



The Cockerill 700 horse-power gas engine and blowing cylinder at the Paris Exposition of 1900.

These tests were conducted by Professor Hubert, of Liege; Mr. Witz, of Lille; Mr. Bryan Donkin, of London; Professor Meyer, of Göttingen, and Professor Dwelshauvers, of Liege. Taking the tests, together with the fact that the engine has actually been blowing a blast furnace for nearly a year, and the question which was proposed by Thwaite has its complete and satisfactory solution. In five short years the problem has been practically solved, and an economic revolution in the working of blast furnaces is but the matter of application of the results already proved possible.

The large engine and blower shown by this company at the Paris Exposition was a duplicate of the one under discussion. It is rated at 700 horse-power on blast furnace gas, 800 on producer gas and 1,000 on illuminating gas. It was run daily for an hour, and was always surrounded by an interested group of sight-seers. Its approximate cost is given at less than $30,000, or, roughly, $40 per horse-power. This is not far from that of modern steam blowing engines, leaving out the cost of boilers and their maintenance. One may also imagine the possibility of rebuilding our horizontal blowing engines, with their steam and blast cylinders tandem, into gas engines, by replacing the steam cylinder by a gas cylinder and making the blast cylinder quicker acting.

The Cockerill Company and its concessionaries have in course of construction 35,000 horse-power of their type of engines. Other European firms have probably altogether an equal power projected. Among the actual plants now in operation are the following:

Seraing, Belgium, four 500 horse-power motors, running blowing engines.

Differdingen, Luxembourg, four 500 horse-power motors.

Hoerde, Westphalia, two 600 horse-power and two 1,000 horse-power motors, running dynamos and therewith manufacturing calcium carbide. Total, 3,200 horse-power.

Friedenshütte, in Upper Silesia, two 200 horse-power and two 300 horse-power; total, 1,000 horse-power. Used for electrical purposes.

Oberhausen, one 600 horse-power engine.

Dudelingen, two 600 horse-power and two 1,000 horse-power; total, 3,200 horse-power.

Kneutingen, two 500 horse-power for blowing.

Roechling, one 200 horse-power, two 600 horse-power.

Ruhrort, one 500 horse-power.

Barrow, England, 1,000 horse-power.

Toula, near Moscow, three 600 horse-power engines for blowing, and three 200 horse-power engines to run an electric plant; total, 2,400 horse-power.

Island of Elba, 1,000 horse-power.

In order to discuss the application of this great economy to American blast furnace practice, we must confess, to start with, that not one single example can be yet cited. Why this is so is hard to surmise; many reasons, or, rather, excuses, may be advanced; possibly our iron works have been so busy making money during the last two years that they have had no leisure to consider the question fairly and on its merits.

European practice, to start with, provides us with all the data necessary for discussing the question of applying this improvement to American blast-furnace practice. To bring out the great saving of power possible under the different conditions which may prevail in different localities and in different practices of driving furnaces, I have calculated the minimum, the average and the maximum surplus of power which may be obtained by replacing our present boiler and steam engine plants by gas engine plants. The calculations are all made on the basis of a production of 100 metric tons (98·57 long tons) of pig iron produced per day.

CASE I.—*To find the minimum surplus power.* Let us assume:

(1) A poor gas, ratio CO_2 to $CO = 3$ to 5 (by volume), with the composition by volume—

CO_2	15
CO	25
H	2
CH_4	1
N	57

(2) A very low fuel consumption of 700 kilos per ton of iron (1,550 pounds).

(3) A high temperature of the blast, 700° C.

(4) The requisite quantity of blast supplied at a maximum pressure of 1·33 atmospheres (nearly 20 pounds per square inch).

(5) The hot-blast stoves to have a minimum efficiency (50 per cent.) and therefore to take away a maximum proportion of the gases.

CASE II.—*To find the average surplus power.* Let us assume:

(1) An average gas, with CO_2 to $CO = 1$ to 2, by volume, and composition by volume—

CO_2	12
CO	24
H	2
CH_4	2
N	60

(2) An average fuel consumption of 900 kilos per ton of iron (2,000 pounds per long ton).

(3) An average temperature of blast, 550° C.

(4) The requisite blast supplied at 0·67 atmosphere (10 pounds per square inch).

(5) The hot-blast stoves to have average efficiency (65 per cent.).

CASE III.—*To find a maximum of surplus power.* Let us assume:

(1) A rich gas, with CO_2 to $CO = 1$ to 5, by volume, and composition by volume—

CO_2	6·0
CO	30·0
H	0·5
CH_4	0·5
N	63·0

(2) A maximum fuel consumption of 1,045 kilos per ton of pig iron (2,400 pounds per long ton).
(3) A minimum temperature of blast, 400° C.
(4) The requisite blast supplied at a minimum pressure, 0·33 atmosphere (5 pounds per square inch).
(5) The hot-blast stoves to have a maximum efficiency (80 per cent.).

We shall then obtain by the proper calculations the following results as to the surplus power obtainable by using boilers and steam engines on the one hand, or gas engines on the other:

	Case I.	Case II.	Case III.
Volume of gases per 100 k. of iron in m^3	307	404	503
Calorific power of gas per m^3	900	953	986
Calorific power of gas per 100 k. of iron	276,300	385,012	495,958
Assume 10 per cent. lost by leakage	27,630	38,501	49,596
Net power of remaining gas	248,670	346,511	446,362
Weight of blast, in kilos, per 100 k. of pig iron	312	388	462
Volume of blast, in m^3, per 100 k. of pig iron	241	300	357
Heat units in the blast	80,210	60,900	48,362
Heat to be supplied the ovens	160,460	93 700	60,450
Net calorific power of the gas left over for boilers or gas engines	88,210	252,810	385,910
Equivalent horse-power of above gas, at an efficiency of 100 per cent., expressed per 100 tons of pig iron produced daily	5,770	16,500	25,200
Indicated horse-power developable by gas engines using this gas at an efficiency of 30 per cent.	1,730	4,950	7,560
Indicated horse-power necessary for furnishing the blast, plus 10 per cent. for hoisting, pumping, etc.	640	460	270
Surplus indicated horse-power, using gas engines, per 100 tons of pig iron produced daily	1,090	4,490	7,290

Remarks.—The surplus of 1,090 horse-power obtainable in Case I is obtainable, according to the assumptions made, when all the conditions are the most unfavorable for the generation of power from the gases. These assumptions agree with the best modern practice in all points except the last, *i. e.*, the minimum efficiency of the stoves. It needs no argument to prove that a plant using the minimum of fuel and maximum temperature and pressure of blast would be necessarily a plant with stoves of the most approved type and efficient working. If we were to make this one change in the assumptions, and assume that instead of using stoves with an efficiency of only 50 per cent., there were used modern stoves with 75 per cent. efficiency, there would result a theoretical development of 2,780 horse-power in the gas engines, or a surplus above that required for the furnace itself of 2,140 horse-power. This, then, is the final estimate of the minimum surplus power to be obtained from a modern blast furnace running on the most economical conditions as regards the production of pig iron—reckoned per 100 tons of pig iron daily.

Case II gives a figure which applies, not to the latest type of furnace practice, but to the average type of furnace making 100 to 200 tons of iron per day—such furnaces as represented good working twenty years ago, and many of which are in operation yet east of the Alleghenies.

Case III represents a figure which is approximated by small, old-fashioned furnaces with a high fuel consumption—in other words, average practice of thirty or forty years ago. The one exception to be taken to this statement is that the stoves are assumed to have a maximum efficiency. If they have a minimum efficiency, the figure would be cut down some; but it is only a rough approximation at the best, and an actual illustration to be given will show that it is not higher than has occurred in actual practice.

To prove the correctness of these general conclusions, it will be interesting to check the figures as to horse-power by calculating the power actually raised by steam boilers and engines, and seeing if this coincides with actual results of practice. To do this we will take the surplus gas and assume it thus converted into mechanical power, at a total efficiency of 3 per cent. (average poor practice), 6 per cent. (average good practice) and 12 per cent. (best attainable practice).

		Case I (*a*).	Case I (*b*).	Case II.	Case III.
Horse-power of gases per 100 tons of pig iron daily, at 100 per cent. efficiency		5,770	9,260	16,500	25,200
Indicated horse-power necessary for running the furnace, per 100 tons daily		640	640	460	270
(1)	Indicated horse-power by steam power at 12 per cent. efficiency	690	1,110	1,980	3,000
	Surplus power, on this assumption	50	470	1,520	2,730
(2)	Indicated horse-power by steam at 6 per cent. efficiency	345	555	990	1,500
	Surplus power, on this assumption	[— 295]	[— 85]	430	1,230
(3)	Indicated horse-power by steam at 3 per cent. efficiency	170	280	495	750
	Surplus power, on this assumption	[— 470]	[— 360]	35	480

Case I (*a*) represents Case I of the previous calculations, *i. e.*, best modern practice with *poor* stoves. Case I (*b*) is the modification which considers best modern practice, using good efficient stoves.

The figures of assumption (1) above are highly theoretical, inasmuch as they represent the very best attainable practice with the best engines and boilers, kept up to their highest efficiency. These figures parallel those of Mr. Gordon, calculated on this assumption, contained in his paper in the *Iron Age*, of October 18, 1900. Considering the difficulties of blast furnace practice, they are an unattainable ideal. They show a moderate surplus in the case of best modern practice, and a large surplus of 1,520 horse-power in the case of average practice.

The figures of assumption (2) really represent nearly the best of modern furnace attainment. They show just about sufficient power raised to run the furnace in good practice with low fuel consumption, and a modest surplus of 430 horse-power in average practice.

The assumption (3) is nearer the average of small blast furnace steam plant efficiency, and shows a decided deficit of power for good running with low fuel consumption, and just barely sufficient power in the average running.

We will close by making some specific applications of these calculations to actual American practice, in order to check off the general reliability of the conclusions so far stated.

CASE III.—As an interesting illustration we will take the working of a small spiegeleisen furnace in Eastern Pennsylvania, which, as far as fuel consumption and general efficiency is concerned, will represent fairly well the conditions of our case, and may be taken as typical of the features of the small furnace of fifty years ago.

CONDITIONS.

Composition of gas by volume :

CO_2	3
CO	33
H	2
N	62

Spiegel produced	6,818	kilos daily.
Fuel used	29,000	" "
Flux used	19,500	" "

Carbon in spiegel	4	per cent.
" " fuel	85	" "
" " flux	11	" "
Efficiency of stoves	30	" " (iron pipe stoves).
Gas lost by leakage	10	" "
Pressure of blast	0·75	kilos per c.m². (11 pounds per inch).

RESULTS OF CALCULATIONS.

Calorific power of gas	1,052 calories per m³.
Volume of gas per day	137,204 m³.
Calorific effect " "	144,338,000 calories.
Required to heat blast, per day	50,000,000 "
Indicated horse-power of engine and pump	150

CONCLUSIONS.

Calorific effect of gases, per day		144,338,000	calories.
Lost (10 per cent.)	14,433,800		
For heating blast	50,000,000		
		64,434,000	"
Surplus for burning develops		79,900,000	"

Horse-power at 100 per cent. efficiency	5,200	horse-power.
Developable by steam at 3 per cent. efficiency	165	"
" " gas engines at 30 per cent. efficiency	1,650	"
Surplus power using steam	15	"
" " " gas engine	1,500	"

Remarks.—This little furnace barely raised enough steam power for its own needs. Using gas engines, there would have been a surplus of 1,500 horse-power, which is *at the rate of 22,000 horse-power per 100 tons of product per day.* This 1,500 horse-power would be sufficient to supply all the power needed in the works to which the furnace is attached, and save at least $50 worth of coal per day. It is to be understood that this furnace is an extreme case, and is cited simply to illustrate the general correctness of the conclusions of Case III.

CASE I (*b*).—We will present an example of very good modern practice, with exceptionally low fuel consumption (leaving the average case to the last, because of its greater relative importance).

The data are from a paper by J. Whiting, in the *Transactions of the American Institute of Mining Engineers*, June, 1891, and concern a furnace of the Illinois Steel Company, in South Chicago. The gases were exceptionally poor, the ratio CO_2 to CO by volume being 2 to 3, and the fuel consumption only 750 kilos per ton of pig iron (or 1,680 pounds per long ton).

CONDITIONS.

Composition of gas by volume:

CO_2	15·7
CO	23·5
H	1·2
N	59·6

Pig iron produced daily	130 tons.
Fuel used per 100 kilos of pig iron	75 kilos.
Carbon in fuel, 100 kilos of pig iron	64 "
Carbon in 100 kilos of pig iron	3·75 "
Efficiency of stoves	70 per cent.
Efficiency of boilers and engines	5 "
Volume of blast per minute	247 m^3.
Pressure of blast	0·75 atmosphere.
Temperature of blast	850° C.

CALCULATIONS.

Calorific power of gas per m^3	743
Volume of gas per 100 kilos of pig iron	332·5 m^3.
Calorific power of gas per 100 kilos of pig iron	247,000 calories.
Required to heat blast, per 100 kilos of pig iron	125,854 "
Indicated horse-power of engines per 100 kilos of pig iron	220 horse-power.

CONCLUSIONS.

Calorific effect of gases per 100 kilos of pig iron	247,000	calories.
Lost (10 per cent.)	24,700	
Heating blast	97,070	
	131,770	"
Surplus for burning can develop	115,230	"
Surplus develops per 100 tons iron per day	115,230,000	"
Horse-power, at 100 per cent. efficiency	7,530	horse-power.
Horse-power by steam at 5 per cent. efficiency	375	"
Surplus power per 100 tons output daily	155	"
Developable by gas engines at 30 per cent. efficiency,	2,260	"
Surplus power per 100 tons output daily	2,040	"

Remarks.—This result is 100 horse-power less than the minimum before calculated, but a large allowance of 10 per cent. has been made here for loss, and a reduction of 1 per cent. in this item would increase the surplus power 160 horse-power. The great loss of gas occurring during charging and by leakage is an item which is being rapidly reduced by economical managers.

CASE II.—To illustrate this case, that of average blast furnace practice, we will take the data from a blast furnace plant in Eastern Pennsylvania, which is making in three furnaces 2,600 tons of pig iron a week.

CONDITIONS.

Composition of gas by volume:

CO_2	9
CO	27
H	1·8
N	62·8

Pig iron produced daily	370 tons.
Fuel used per 100 kilos of pig iron	100·0 kilos.
Carbon in fuel, 100 " " "	82·9 "
" " flux, 100 " " " "	4·6 "
" " 100 " " " "	3·1 "
Efficiency of stoves	60 per cent.
" " boilers and engines	4·5 " "
Pressure of blast	1·3 kilos per cm² (20 pounds per square inch).
Temperature of blast	555° C.

CALCULATIONS.

Calorific power of gas per m³	873 calories.
Volume of gas per 100 kilos of pig iron	434·7 m³.

Calorific effect of gas per 100 kilos of iron . .	379,490	calories.
Required to heat blast, per 100 kilos of iron .	90,500	"
Indicated horse-power of engines for blast . .	950	horse-power.
" " " " " hoist, pumps, etc. (per 100 tons of iron daily) . .	65	"

CONCLUSIONS.

Calorific effect of gases per 100 kilos of pig iron,		379,490	
Lost (10 per cent.)	37,950		
For heating blast	90,500		
		128,450	calories.
Surplus for burning develops		251,000	"
Surplus per 100 tons of pig iron daily . . .		251,000,000	"
Horse-power, at 100 per cent. efficiency . .		16,400	horse-power.
Horse-power with steam, at 4½ per cent. efficiency		738	"
Deficit of steam power, per 100 tons iron daily		**277**	"
Horse-power with gas engines, at 30 per cent. efficiency		4,920	"
Surplus power with gas engines (per 100 tons daily)		**3,900**	"
Deficit of steam power per 370 tons daily . .		**1,025**	"
Surplus of gas engine power per 370 tons daily		**14,400**	"

Remarks.—It is an actual fact that, at the works in question, the three blast furnaces are *charged* with 800 horse-power, furnished to them by the boiler plants fired by coal. It is also a fact that nearly 10,000 horse-power is raised for the rest of the plant by coal-fired boilers, and that *all of this* could be supplied by gas engines utilizing the blast furnace gases. The saving in the coal bill alone would amount to at least $150,000 in one year. The gas engine plant to accomplish this would cost $500,000.

Conclusion.—I have chosen to conclude with this case in order to leave an adequate impression of the great industrial revolution which is imminent in the economical utilization of blast furnace gases.

METALLURGICAL DEPARTMENT, LEHIGH UNIVERSITY,
November 2, 1900.